THE UNIVERSITY OF ALBERTA

MDES FINAL VISUAL PRESENTATION

by

XIAOYU ZHOU

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF DESIGN

IN

INDUSTRIAL DESIGN

DEPARTMENT OF ART AND DESIGN

EDMONTON, ALBERTA

FALL 1998

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled:

Design for SCUA - Solar Car of the University of Alberta

submitted by XIAOYU ZHOU in partial fulfilment of the requirements for the degree of Master of Design.

The University of Alberta

RELEASE FORM

NAME OF AUTHOR ___XIAOYU ZHOU___TITLE OF THESIS DEGREE

FOR WHICH THESIS WAS GRANTED __MASTER OF DESIGN__YEAR

THIS DEGREE WAS GRANTED ___________1998___________

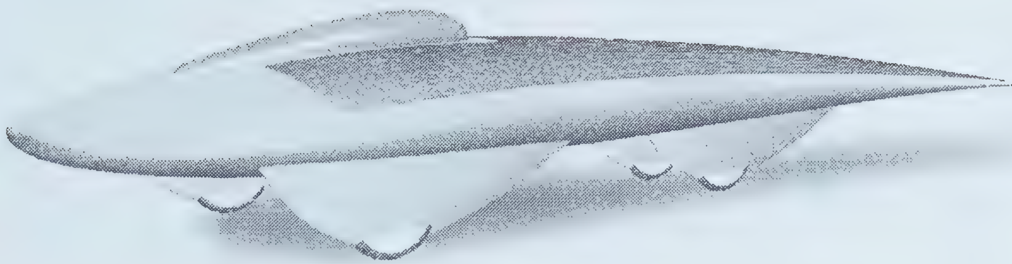
DEPARTMENT OF ART AND DESIGN

GRADUATE STUDIES

UNIVERSITY OF ALBERTA

I hereby release the following works for incorporation into the University Collections, University of Alberta, as part of the Master of Design Thesis Collection:

TITLE	DATE	MEDIUM	SIZE



Support material for a Master of Design thesis by project in Industrial Design

Design for SCUA

Solar Car of the University of Alberta

By
Shawyu Zhou

Industrial Design
Department of Art and Design
University of Alberta

December, 1998

Abstract

This report documents the design of a solar car in collaboration with the Engineering Faculty at the University of Alberta. The responsibilities in the design process are design management. design research, shell design, cockpit design and design for fabrication. The report explains how these responsibilities were addressed and discusses the results of the design. The project exemplifies the value of interdisciplinary collaboration.

Acknowledgement

Thanks to UASVP Group members for their support.

Also thanks to the staff and my friends for their help.

Bruce Bentz, MFA, MDes
Professor
Industrial Design
University of Alberta

Douglas W. Lindstrom, Ph.D.
Instructor
School of Mechanical and Manufacturing Technology
The Northern Alberta Institute of Technology

Desmond Rochfort, Ph.D.
Professor and Chair
Department of Art and Design
University of Alberta

Gajewski, Cezary	*MFA*
Horne, Ken	*BA*
Kurzitza, Roland	*MDes*
Lederer, Robert	*MDes*
Rose, Keith	*MFA*
Wolodko, John	*Ph.D.*

A special thanks for the enthusiastic help of

Richard Butchart
EDS Sunrayce Aerodynamics Leader

Table of Contents

1 SCUA Project Background

1.1 project statement

1. Context

SCUA stands for the Solar Car of the University of Alberta. It was designed for UASVP, the University of Alberta Solar Vehicle Project. The UASVP team is made up of faculty advisors and students from Industrial Design, Engineering and Science, working in the areas of structure and dynamics, power systems, engineering design, construction and project management.

The principle goal of SCUA is to participate in the Sunrayce competition, a 10-day trip down the east coast of the United States from Pennsylvania to Florida which will be held in June 1999 (www.sunrayce.com). Every two years General Motors (GM), Electronic Data Systems (EDS), and the United States Department of Energy (DOE) sponsor Sunrayce, a cross-country race for cars powered entirely by the sun. This race has several purposes: providing research into alternate power sources, promoting conservation of the environment, and offering real-world education for university students. The other goal of SCUA is to participate in the World Solar Challenge competition to be held in October 1999 in Australia which will run across the continent from Darwin to Adelaide (www.wsc.org.au).

2. U of A AFV History

Throughout U of A SAE (the Society of Automotive Engineering) history a series of AFVs (Alternative Fueled Vehicle) have been designed for competitions, such as HEV (hybrid electric vehicle), NGV (natural gas vehicle) and LPGV (liquid petroleum vehicle). The SV (solar vehicle) is the first U of A solar car (www.ualberta.ca/~SAE). A solar car is very different from all the previous vehicles. As the team has no previous experience in this area everything built for the car will be from the ground up.

3. SCUA project statement

The idea of harnessing solar energy for the purpose of powering modes of transportation has been a challenge for many years. With today's increasing population and a dramatic increase in motor vehicles over the last few years, pollution from automobiles has risen to harmful levels. The call has come for an alternative fuel source. This project showcases our desire for increased environmental responsibility which, we believe, can be attained through public awareness of the issues. (www.ualberta.ca/~SAE)

4. My responsibilities in UASVP

In ecology, the harmony of nature and technology can be understood as using technology to serve the environment instead of destroying it. In industrial design, the harmony between nature and technology can be understood as the integration of responsibility, beauty and a man-made product.

Industrial design is a bridge that connects all the technologies that can be applied to the solar car. The industrial designer is a project organizer. SUCA will largely be built from the ground up. The main objective for industrial design in the UASVP is to rationalize the integration of all functioning components. As an industrial designer in UASVP, I have applied modern technology in my design.

My responsibilities in UASVP include design management (shared), design research, shell design, cockpit design and design for fabrication. It should be understood that because the project is interdisciplinary it necessarily involves input from others, namely in Engineering and at Northern Alberta Institute of Technology (NAIT). As a result the lines of responsibility cannot be exactly drawn. However, in the report I will, as clearly as possible, state my contributions to the project and the nature of my collaboration with others.

1.2 Solar energy and solar cell operation

1. About solar energy

As people vie for the remaining stores of fossil fuel, the so-called natural energy resources, sun and wind, assume an enormous role. Solar energy is the essential clean energy. Whereas fossil fuels pose serious pollution problems.

The sun generates energy through nuclear reactions in its core (principally the conversion of hydrogen to helium) at temperatures in excess of ten million degrees. This energy is carried to the sun's surface, which then radiates at a temperature of approximately 5800 K.

The flux received from the sun at the top of the earth's atmosphere is known as the solar constant at about 1353 Watt/m^2. At the earth's surface the solar flux is reduced to approximately 1000 Watt/m^2 (when the sun is directly overhead).

Throughout history people have tried various ways to make use of solar energy. The modern technological solar energy application dates back to the 1950's. The introduction of doped semiconductors marked the beginning of the modern solar cell.

2. About the solar cell

Solar cells are made using semiconductors such as silicon. Semiconductors are useful materials because they can be doped with impurities to change their electrical properties, forming either 'positive' (p-type) or 'negative' (n-type) material. A solar cell consists of a layer of p-type and a layer of n-type semiconductor sandwiched together to form a p-n junction (refer to fig. 1).

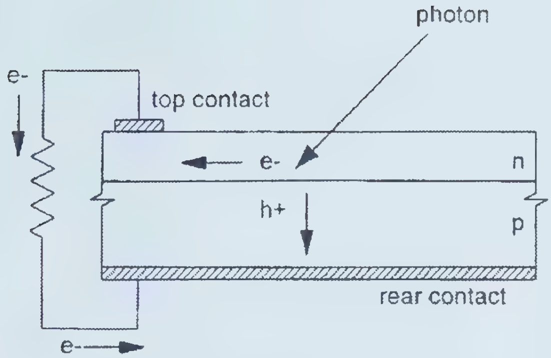


Figure 1. Cross-sectional view of a solar cell

This p-n junction induces a fixed electric field. When the device is exposed to light, consisting of photons, some of the incident photons are absorbed and temporarily liberate electrons from their covalent bonds in the crystal lattice. This can only occur if the energy of the incident photon is greater than the amount of energy required to break the covalent bond, known as the bandgap energy. Each liberated electron leaves behind a hole (a space once occupied by an electron), which acts as a positive charge. In an ordinary semiconductor material, these electron-hole pairs recombine after a short time. In a solar cell, however, the electric field formed by the p-n junction attracts electrons to the n side and holes to the p side. This charge separation induces a voltage across the device. When the two sides of the p-n junction are connected together via an external circuit, current is able to flow, thus producing electrical energy. (Roche, M. David)

2 Design Management

The schedule below is a generalized overview of project components, participants and projected dates. As of this writing , November 1998, the schedule is realistic.

Conception of SCUA	01/30/98

Resources

Time	Money	Technology	Technique Support

Defining SCUA	02/10/98

I. D.	Mec. E. & Civil E.	E. E.	Arts & Education

Planning	02/20/98

Body	Suspension	Motor	Solar Array	Instrumentation	Finance
Cockpit	Brake	Controller	Battery		Education
	Wheels	Transmission			

Team Design	09/30/98

Collection of data

Analysis of data

Development of alternatives

Selection of solution

Design Implementation	02/29/99
SCUA Testing & Modification	05/31/99

Safety	Strategy	Telemetry	Weather Predication

Race Participation	06/10/99

3 Design Research

3.1 Principles

1. Basic physics

A solar car is an electric vehicle that generates its power directly from the sun, usually through an array of photo-voltaic cells. The generated energy is then stored in the car's batteries so it can be used at any time.

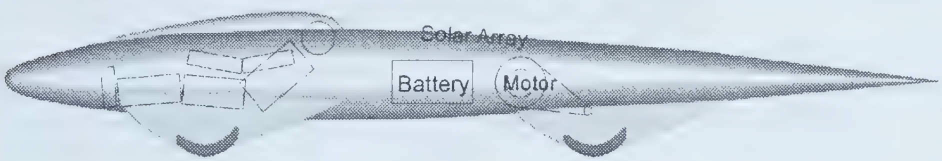


Figure 2. Solar car driving components

Both speed and reliability are necessary for the success of a solar car.

From $P = FV$ (P: output, F: force, V: velocity)

and $E = 1/2mV^2$ (E: energy, m: mass, V: velocity),

we know that V, speed, is directly proportional to output and inversely proportional to force and square root mass. In order to increase speed, we should increase output as well as reduce drag and mass.

2. Principles for solar racing car aerodynamics

The ideal aerodynamic shape has no lift, no down force, very little drag, and stability during cross winds. Drag consists of air drag and road friction. In order to minimize drag, we should improve aerodynamic performance and reduce the friction between the tires and the road.

According to Humphris, Clive there are ten principles for solar racing car aerodynamics
Rules for reducing air drag

1) It is essential to ensure attached flow over every surface of the vehicle.

2) Wetted area (the area that is covered by fluid flow) should be minimized while ensuring that flow remains attached.

3) Laminar boundary layer flow should be maximized and thus cover as much of the vehicle as possible.

4) Surface finish should be of as high a standard as the budget of the team will allow.

5) Solar car should produce zero lift. According to $C_{di} = C_l^2/(\pi A)$ *(C_{di}: induced drag coefficient, C_l: lift coefficient, A: aspect ratio)*

6) Wing tip drag should be minimized by a combination of thinning and rounding the lateral edges of the body to reduce this drag.

7) The frontal area should be minimized consistent with the first six rules. According to $F_d = (C_d A V^2)/391$ (F_d, aerodynamic drag, A, frontal area, V, velocity)

8) Interference drag should be minimized.

9) Ventilation drag should be minimized.

Rule for side wind stability

10) The side force area should be minimized and it should be biased behind of the center of gravity.

These principles were carefully considered and adhered to in the design of SCUA. In addition, SCUA should be as light as possible. In order to make SCUA reliable we should try to avoid any possibilities for damage or failure. SCUA should be built to be strong and stable. Also, most of the important components should be repairable.

3. Race Restrictions

According to the race rules (refer to www.sunrayce.com and www.wsc.org.au. The articles of rules are too long to be contained in this thesis.), the area of solar array must not exceed 8 m^2. Every team has the same maximum area restriction. Thus, efficiency is of the highest priority for a solar car. Solar cars are run by converting solar energy from solar cells into electrical energy, supplying that energy to a battery or motor via a DC/DC converter, and using the rotational energy of the motor to drive the wheels. For cars to be built to racing specifications, designers must understand efficiency in terms of the elemental technologies relating to solar cells, car bodies, batteries, and motors.

3.2 Design scope

1. Shell design

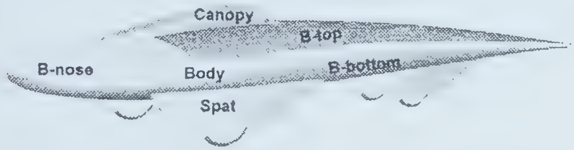


Figure 3. Shell components

The shell design includes aerodynamic design and shell structure design. An aerodynamic design reduces air drag and increases car stability during driving. Shell structure design makes the shell strong enough to withstand it's own weight (including the solar array) and external impact, and makes it 'operable' (e.g., the assembly and the disassembly of the top part and the fit between the frame and the shell).

The shell includes the body, the canopy and the 4 spats. Using the mold part line, the body can be divided into the nose, the bottom and the top. The solar array covers the entire top area.

2. Cockpit design

The cockpit design includes seating design and control interface design. The cockpit design must be ergonomically designed to rationalize driver comfort and performance.

3. Design for fabrication

Design for fabrication includes three stages, design for plug fabrication, design for mold fabrication and design for shell fabrication.

3.3 Body Structure types

1. Three most popular types of body structure:

Some form of structure is required to support the car body. One typical form is a space frame made of linear elements which can be fabricated out of variety of materials. A typical frame is shown below.

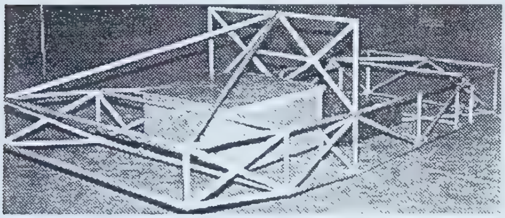


Figure 4. Space-frame

This is the space-frame chassis of tubular alloy members with a separate composite body. The following are the properties of some alloys used in solar race cars.

Alloy	Tensile strength(MPa)	Young's modulus(GPa)	Density(g/cm^3)
Mild steel	400	210	7.80
Magnesium(AZ31b)	250	45	1.77
Aluminum 6061 T0	124	70	2.72
Aluminum 6061 T6	310	70	2.72
Titanium B 120VLA	1379	110	4.85
Chromoly 4130	2068	205	7.90

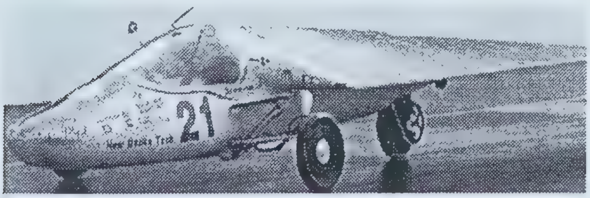


Figure 5. Monocoque

Monocoque construction makes very efficient use of materials. It uses a single component, the skin, to perform two tasks—provide the outer surface of the car and act as a structural member—and thereby saves weight. It also allows an uncluttered internal space.

The usual design uses sandwich material of either an aramid fiber or a carbon fiber in an omni-directional weave on either side of a foam or honeycomb material; frequently Nomex, although sometimes aluminum honeycomb is used. These preformed sheets of material are readily obtainable, and can be cut, shaped and bonded fairly easily. (Schinckel, Antony)

The following are the characteristics of composite materials used in race solar cars.

Fiber	Tensile strength(MPa)	Young's modulus(GPa)	Density(g/cm^3)
E-glass	3448	73	2.54
S-glass	4482	86	2.49
AS-4 carbon	4000	228	1.80
IM-7 carbon	5413	276	1.77
P-100 carbon	2241	690	2.16
Kevlar 49 aramid	3792	131	1.47
Boron	3516	400	2.49
Wood	100	8-13	0.40-0.80

A common way of using composite materials is in a sandwich structure. This consists of a high strength composite layer bonded to both sides of a low weight core. The main materials used for the skin of the sandwich in the race solar cars were carbon fiber in its various forms, E-glass, and Kevlar or its equivalent. Nomex honeycomb or some other aramid variant was the most common core material. Reinforcing to local joints was often performed with glass tape or unidirectional carbon fiber tape impregnated with epoxy resin (pre-preg).

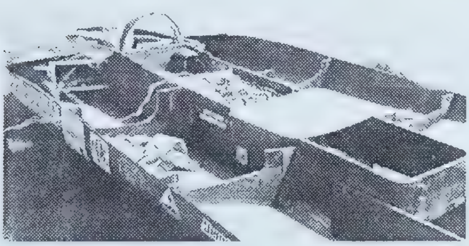


Figure 6. 'Tub'

One of the most common chassis types is that of a multiple 'tub' chassis; a semi-monocoque arrangement with longitudinal and rib members, usually made of a sandwich material. The tub is, in some sense, a hybrid of the space-frame and monocoque approaches. (Schinckel, Antony)

It is frequently difficult to classify a vehicle as being in one category or another, since boundaries are extremely blurred.

2. Cockpit construction types

The design for the seat determines the type of cockpit because the seat occupies the most space in the cockpit. Seats varied greatly. Some teams used bare composite shells to which 10 mm of sponge had been glued. The University of New South Wales seat (Fig.7) is typical of many composite seats. Some seats were merely spaces large enough, dimensionally, to accept a human form.

Some teams used a version of a hammock type seat. These seats were usually made of a synthetic material in a coarse mesh. The advantage of this type of seat is that it is extremely light, fairly comfortable, fits a variety of body sizes, and exposes some additional surface area of the body to air circulation, thus increasing cooling.

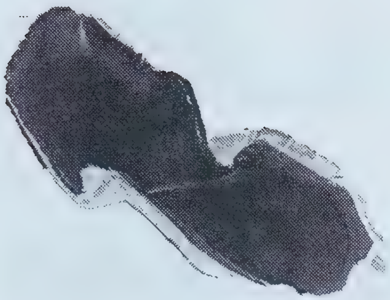


Figure 7. The carbon fiber seat from the University of New South Wales

3.4 External Body types

A unified aerodynamic body is the most popular solar car shape and integrates the body and solar panel into a single aerodynamically shaped package.

The design allows for a small frontal area, low weight, and a wide range of visibility around the canopy. Fixed or tilting, flat panels with a separate driver cab are simple, lightweight, and inexpensive to construct; however, aerodynamic efficiency is compromised due to exposed suspension components and vulnerability to cross winds.

After I reviewed almost all the solar cars that entered Sunrayce, WSC, and other solar car race competitions, I discovered that nearly all of unified solar cars can be found in the following three types. I also collected some configurations of each example.

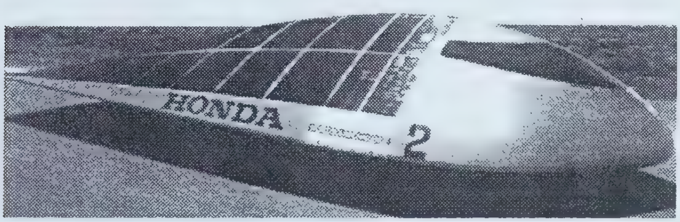


Figure 8. 'Cockroach'

Honda Dream, winner of WSC '93, exemplifies the 'cockroach' shape, with a forward fully-enclosed canopy.
Chassis: carbon fiber reinforced aramid honeycomb tub
Body: carbon fiber reinforced aramid honeycomb tub

Figure 9. 'Flat array and forward bubble'

Solar Eagle III, winner of Sunrayce '97, used a flat array and forward bubble canopy.
Chassis: carbon fiber monocoque structure
Body: carbon fiber skin with Nomex honeycomb core

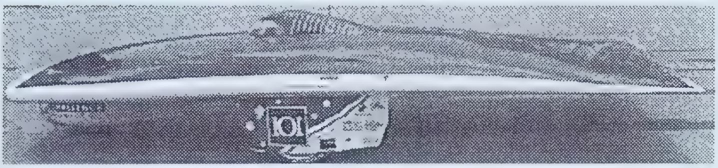


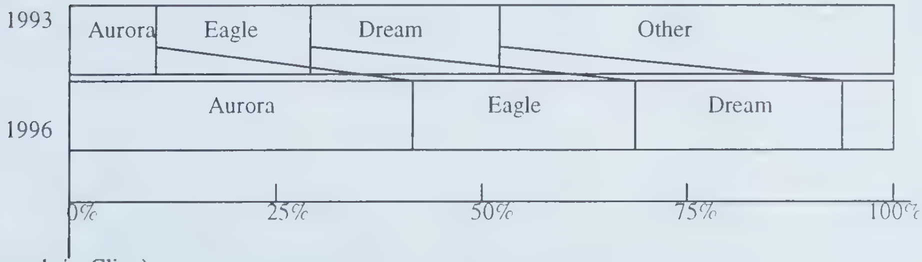
Figure 10. 'Driver centered'

Aurora 101 placed the driver canopy in the center of the array, to minimize wetted surface area.
Chassis: carbon fiber reinforced Nomex monocoque
Body: carbon fiber reinforced Nomex monocoque bottom

Comparison of drag coefficients based on wetted and total surface areas for these 3 types.

Vehicle	Drag area (m^2)	C_d based on frontal area	Frontal area (m^2)	C_d based on wetted area	Estimated wetted area (m^2)
Aurora	0.090	0.120	0.75	0.0045	22.8
Eagle	0.143	0.130	1.10	0.0067	21.5
Dream	0.114	0.100	1.14	0.0052	22.0

Percentage of vehicles adopting various body styles for 1993 and 1996 WSC, showing trends in vehicle design over the history of the event.



(Humphris, Clive)

4 Discussion of Research

4.1 Body Aerodynamic Analysis

1. Body external type comparison

To win a race, solar cars must travel at speeds approaching 100km/h on less than 1.5kW. To attain such high efficiency, solar car designers must refine all systems that consume energy, but above all they must achieve extremely low aerodynamic drag. Power collection is one of the highest design priorities, while aerodynamic drag is the largest retarding drag. Hence, aerodynamics is the most important consideration in my shell design.

The 'flat array and forward bubble' type was chosen for my design from among the 3 car types based on the following reasons.

It resembles the classic airfoil shape which has excellent aerodynamic properties. Its smooth tapering shape ensures a high degree of laminar flow and low skin friction. In particular, the taper virtually eliminates the low-pressure region at the vehicle's rear, creating a very low drag coefficient. Moreover, the cost of solar cells determined that we design SCUA with a fairly flat solar array that was both cheap and easy to handle. Our design was modeled after the Solar Eagle III type with its flat array. In addition, this type is easier to be built compared with the other 2 types, and it is easier to detect if any structural problem occurs.

The 'cockroach' type has a very drastic curved surface that slopes down from front to rear, which results in a good aerodynamic performance. But it also causes the loss of solar array efficiency due to the slope. It was fine for WSC because the sun was always behind the solar cars. However, it is not acceptable for Sunrayce '99 since the sun will always be in front of the cars. To fully enclose the canopy with the body increases the frontal area.

The 'driver centered' type has a very limited extra wetted area excluding 8-m^2 solar array and a limited frontal area, but it has a blunt nose which causes air stagnation in front of the nose and leads to positive pressure. The clearance between the car and the ground should be fairly high for counteracting the road effect. But high clearance creates the difficulty of suspension, steering and drive train design. According to the history of solar car races, this was a problematic area and should be avoided.

2. Discussion of Solar Eagle III

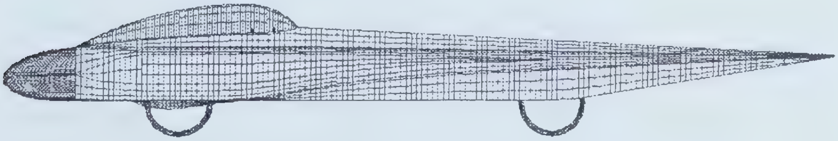


Figure 11. Side view of Solar Eagle III

From the side view of the Eagle, I found there were some problems in terms of aerodynamics. First, the nose is too blunt. Second, the curvature of the bottom part, especially from the front wheels to trail, is too stiff. This would make it difficult to ensure attached flow over every surface of the vehicle. Last, the Eagle

looks like an upside down airfoil, which causes a negative lift. To overcome negative lift, we must consider the influence of the road.

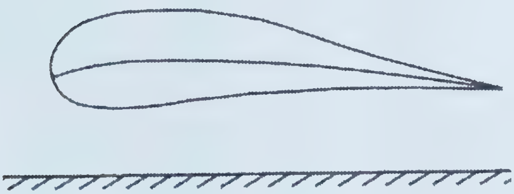


Figure 12. Airfoil

The illustration above is the example of zero lift. To avoid the negative lift, the camber of the body needs to be formed so that the velocity distribution under the body becomes similar to that over the top surface and the total lift force approaches zero.

In designing the car's body, there is a series of trade-offs between aerodynamics and power collection, as well as driver position. An adopted Eagle-type shaped vehicle was a compromise to maximize power collection, minimize aerodynamic drag, and still allow enough space for the driver. I tried to achieve this by combining the advantages of other types into the 'flat array and forward bubble' type.

4.2 Body structure type analysis

Schinckel's brief but thorough analysis compares the three body structure types.

Monocoque structure makes very efficient use of materials, but it also has its obvious disadvantages. First, it requires that the whole vehicle be very much designed and built as a package: the aerodynamic design must be finalised before any part of the body can be built. Secondly, it is not as easy to do the stage-by-stage testing and evaluation that is an attraction of the space-frame and tub approaches. Access to the interior components is frequently more difficult since the skin is an integral structural component, and it is therefore difficult to design with large removable panels that can still act as structural components. Finally it is more difficult to repair than a space-frame chassis.

The tub structure has a potential advantage over the purer monocoque layout, in that the tub can more simply be modeled as a pseudo-space-frame structure, and load paths (static and dynamic, including accident) can be fairly accurately determined. It is much harder to model a distributed structure accurately than it is to model a space frame. The orientation of the fibers plays a crucial part in determining the end product' strength and stiffness in different directions. Continuous fiber materials often have excellent longitudinal strength, but very poor transverse characteristics that may depend on more on characteristics of the matrix media.

Constructed of aluminum, space frames are designed to be the load-bearing component of the car. In general, space frames are very lightweight, inexpensive, relatively easy to design, construct, analyze, test, and modify if need be. Structural failures, or impending failures, are often easy to recognize, manifesting themselves as obvious cracks or bends. Failures in sandwich and composite structures, on the other hand, are usually much harder to detect, since they are not always visible. One major advantage of the space-frame is that the vehicle can be tested in various stages of completion-as a raw chassis and suspension towed behind a support vehicle, for example-then in stages as the various subassemblies are added.

In a number of cases it was not clear whether a vehicle's load-bearing structure should be considered a space-frame with some composite panels added for shear strength, a composite tub chassis with space-frame subframes, or a composite tub with some semi-structural monocoque-like skin surfaces. In fact, an excellent compromise can be achieved by using this hybrid approach. (Schinckel, Antony)

UASVP decided to use a space-frame mixed with this 'hybrid approach'. This adopted space-frame structure has the characteristics of a 'tub' structure.

4.3 Discussion of materials

A true space-frame uses materials efficiently by placing very thin light members in tension and compression. To take full advantage of this, great care is required in the early planning stages of a vehicle to ensure that all load inputs are taken into account, and fed into appropriate nodes. Normally, metals are used in space-frame construction. Aluminum 6061 T6 which is both light and easy to weld was chosen for SCUA. The chassis made of this can only weigh up to 7 kg. Steel was eliminated because of its weight. and Titanium and Magnesium are difficult to weld.

Composite materials are extremely lightweight and very strong; however, the manufacturing process is very detailed and labor intensive. First, molds are made either by CNC milling the body shape from computer data and then the composites are laid up.

Carbon fiber was selected as our main materials for body fabrication. The space frame provides the car structural strength and supports the weight of the skin, the solar array and a possible accidental force. 2~3 layers of carbon fiber are enough to endure the weights and forces.

	Density Kg/m3	Elastic modulus GPa	Stress at failure GPa	Strain at failure %
Hi-strength Carbon	1,950	240	2.8	1.0
Kevlar 49	1,450	120	2.7-3.5	2.0-2.7

From the table, we learn that carbon has a similar density as Kevlar aramid but has better tension and compression resistance. Kevlar has better impact resistance. In other words, carbon is more brittle. Kevlar will be applied to some crucial local area, for instance, some parts of bottom that have to endure the impact of high speed stone and sand.

However, the combining of 'tub' feature in our body structure determines the adoption of sandwich structure in some critical area of SCUA.

4.4 Discussion of Cockpit

The instrumentation team comprised of 2 engineering students is conducting research and will make recommendations upon which I will base my design of an instrumentation panel and drive controls.

For seating, the hammock type exposes some additional surface area of the body to air circulation, which is very important for the driver in a hot environment. But it is too soft to support the driver during several-hour's driving that causes muscle fatigue. The composite type overcomes the problem of support but it surrounds the driver's body too much and it is not good for air circulation. My design task is to try to find a way to combine the advantages of the two types.

5 Shell design

5.1 Conception

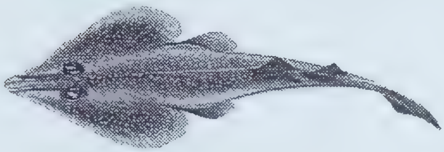


Figure 13. Stingray

Although I got many ideas from other solar car designs during my research, I also adopted forms from nature. An aerodynamic form of solar car should have some similarities with the form of some fish because they both experience fluid drag at a similar Reynolds Number (Re) (i.e., the basic condition for flow similarity of different objects).

$Re = \rho VL/\mu$ (ρ: fluid density, V: velocity, L: length, μ: viscosity)

For a period of 10 months I produced numerous sketches, renderings and models (a selection is represented below). These designs were informed by my research and my understanding of aerodynamic principles.

1. Concept sketches

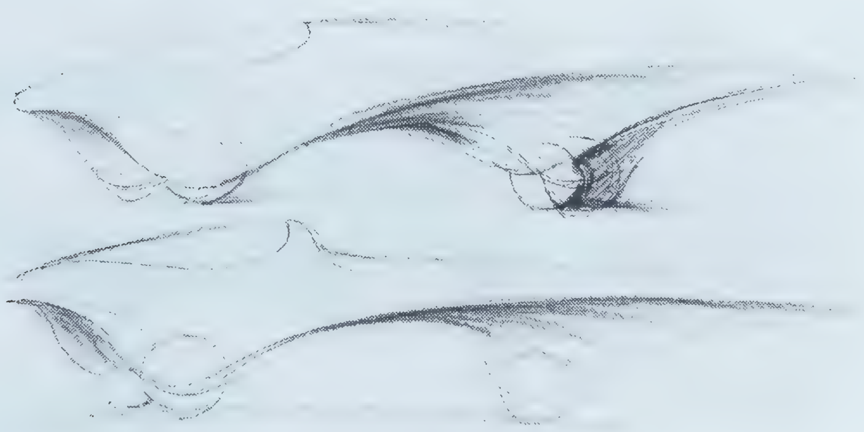


Figure 14

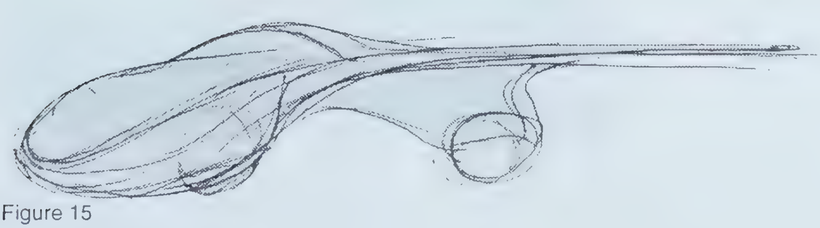


Figure 15

Figure 16

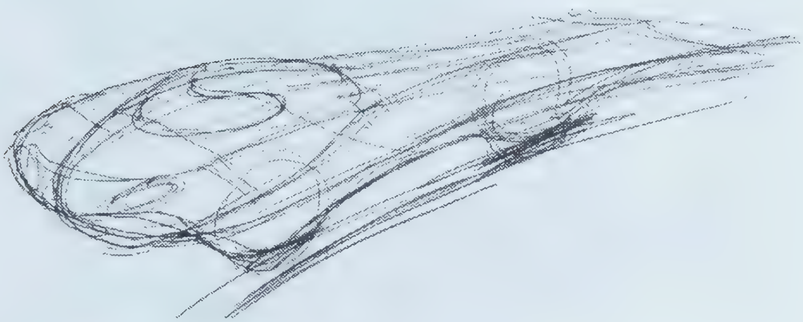


Figure 17

2. Rough models

Figure 18

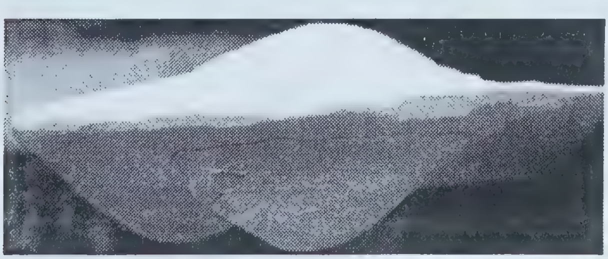


Figure 19

3. Concept renderings

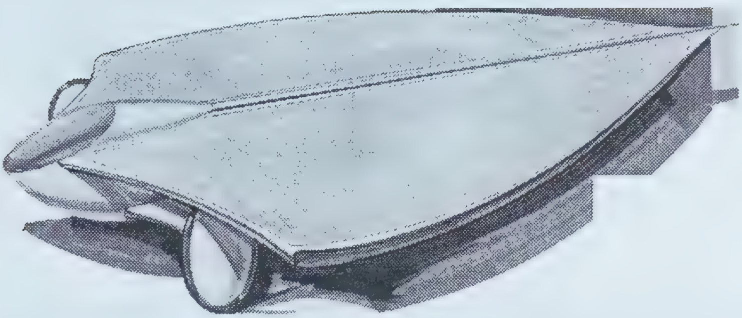


Figure 20

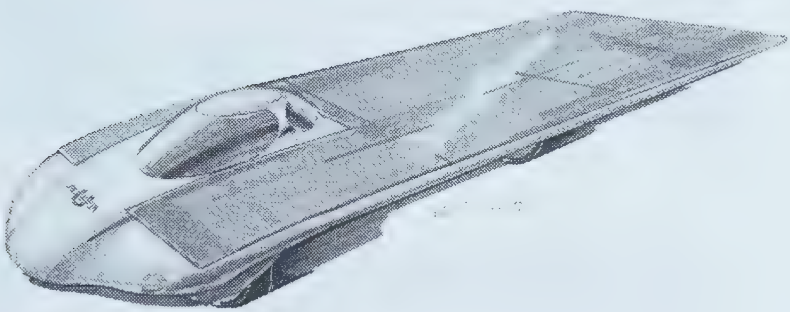


Figure 21

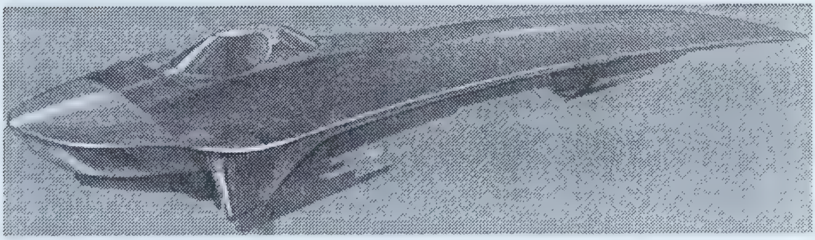


Figure 22

5.2 Computer Models

Materializing my preliminary concepts made it easy to have discussions in numerous meetings I had with my colleagues in Engineering. As our ideas become more focused I was able to move to the computer modeling of designs.

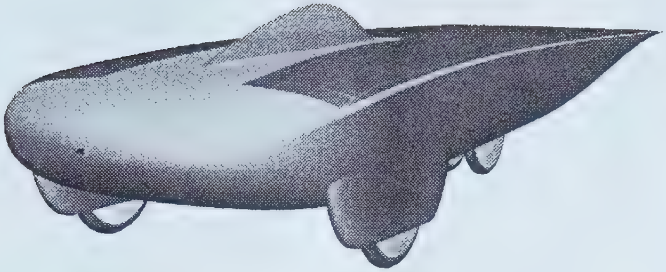


Figure 23. Model 1, file no. 287

Figure 24. Model 2, file no. 359

Figure 25. Mode1 3, file no. 382

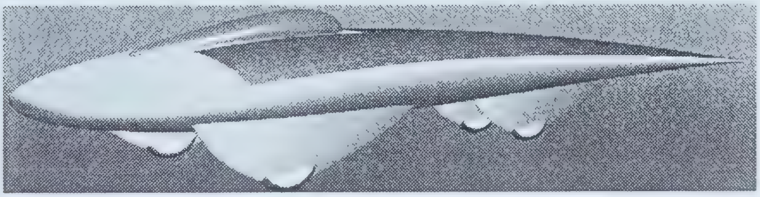


Figure 26 Model 4, file no. 385

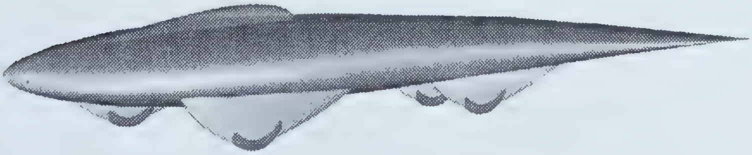


Figure 27. Model 5, file no. 384

This lengthy period of development resulted in a series of computer models that I uploaded via Internet to Richard Butchart, the Sunrayce Aerodynamics leader at the EDS company in the USA. After his analysis of each design he would post the results on the encrypted web pages (A selection of analyzed results can be found in the Appendix I.). To achieve good aerodynamics, body shapes go through a thorough analysis process. Lift, down force, and drag data as well as airflow over the vehicle is gained through wind tunnel testing and computer analysis using the programs VSAERO and OMNI3D. The programs are advantageous because it is easy to quickly run multiple iterations if the body shape changes; however, the drawback is that their results are only estimations.

Each reply would inform my continued refinement of the design. This process finally brought me to our final design (Fig. 27).

5.3 Design for shell parts

1. Car body

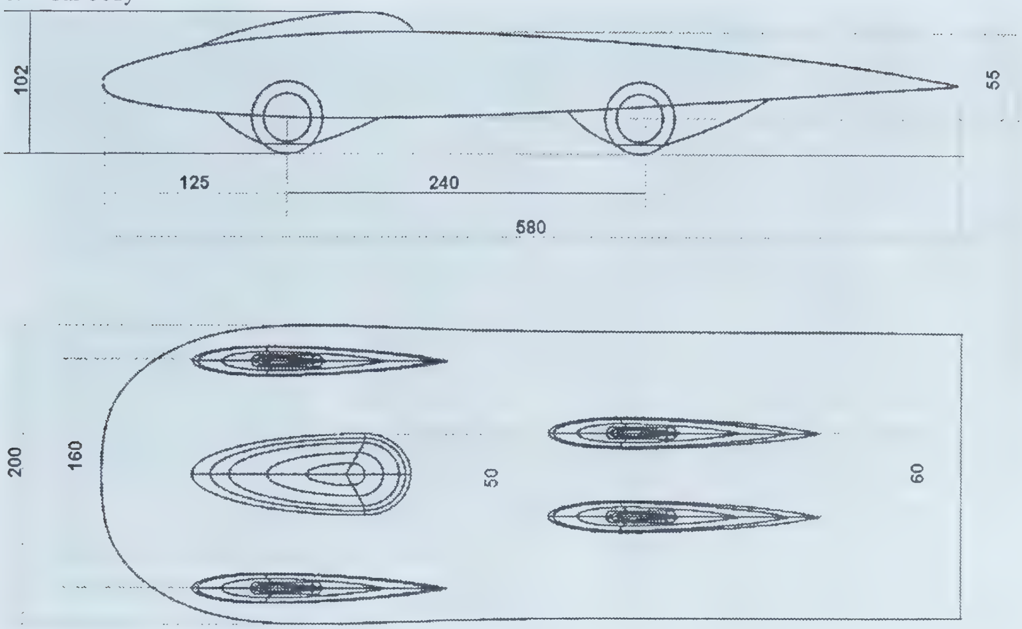


Figure 28. Body Dimensions

2. Canopy

Some typical aerodynamic designs for canopies already exist. They are available through Form/Tec Plastic Company who will custom make our canopy. The product type called 'Airflow' meets our requirements.

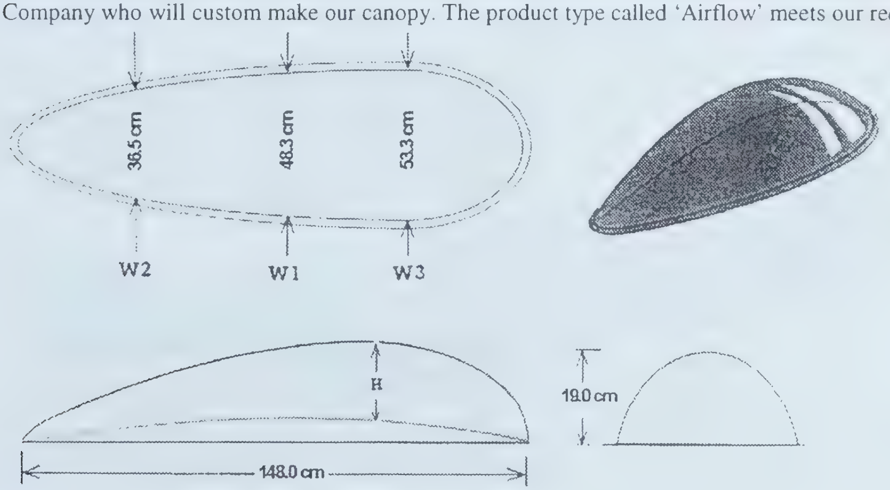


Figure 29. Canopy Dimensions

We chose a canopy design with a height to length ratio of 1:8, which is very close to the ratio of the ideal aerodynamic performance. The actual height is lower than the canopy itself because of the curvature of the car body (bottom left of Fig. 28).

3. Spats design

Spats should cover the wheels entirely and be extended to have good aerodynamic characteristics. Spats should be minimized to reduce both side force area and frontal area. The front wheels are the steering wheels. Deciding to move the spats with the front wheels was a good solution. In my design the spats pass through the body. This requires the parts to be sealed.

4. Design of the body top

The solar array component must be detachable so that the panel can be charged. A 2 cm offset of the solar array area acts as a structure that is easy to handle when it is taken off.

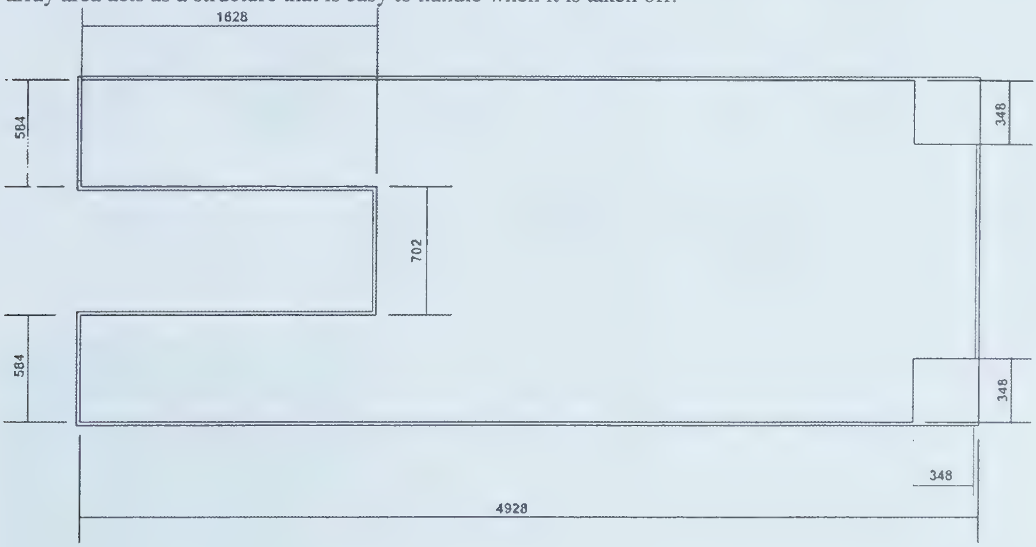


Figure 30

In my design, there are longitudinal and latitudinal ridges for reinforcement. The top part has holes in it to release the heat and to improve the efficiency of the solar cells. The reinforcement is a sandwich structure, which has a carbon fiber cover and a Nomex honeycomb core.

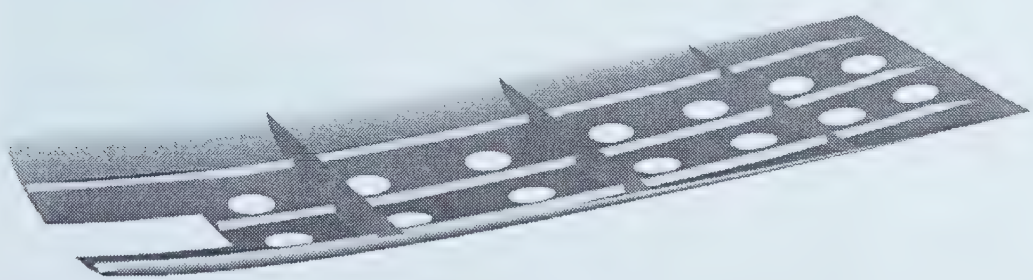


Figure 31

5. Design of the body bottom

The bottom panel has a similar structure as the top panel except for the holes. From this structure, we can see it has the characteristics of a 'tub'.

6 Cockpit design

1. Seating design

The maximum height of our car body is 55 cm. The maximum height of the canopy is 12 cm. As a result, the angle of driver position must be very low.

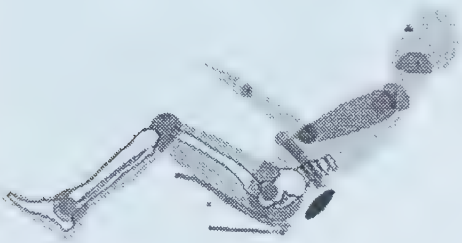


Figure 32. Driving position

I used the seat pan and back pan of the 'Aeron chair' as the driver's seat pan and back pan. The Aeron chair is the product of the Herman Miller Company. Both pans are detachable from the chair and are made of the patented pellicle material stretched on a frame.

Figure 33 Aeron Chair

Pellicle is a breathable membrane which distributes weight evenly—cradling the body so that it 'floats' in the seat without touching the frame. The frame is a synthetic recycled material, light and strong. Frames of both pans each have 4 holes to receive bolts, allowing the detachment of the pans to the space-frame. I chose to use the smallest size 'A' of the Aeron chair which is designed to support people of 130 pounds and a maximum of 5'2" tall.

Subframes (the darker elements) were added to the space-frame structure (the lighter elements) to support seat and back pans (Fig. 34). The angles of 2 pans are set so they are able to provide maximum accommodation for the driver in the limited space (Fig. 35). A roll bar is incorporated to afford the driver adequate protection if the car rolls over. The seat also incorporates a seat belt and a neck support

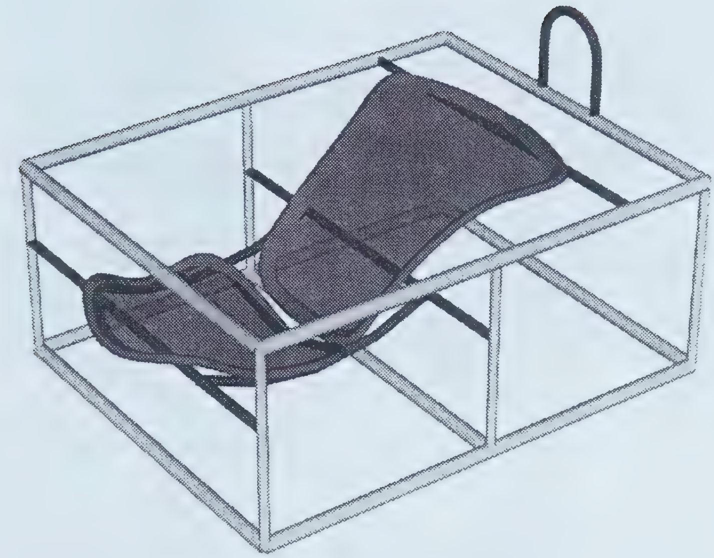


Figure 34

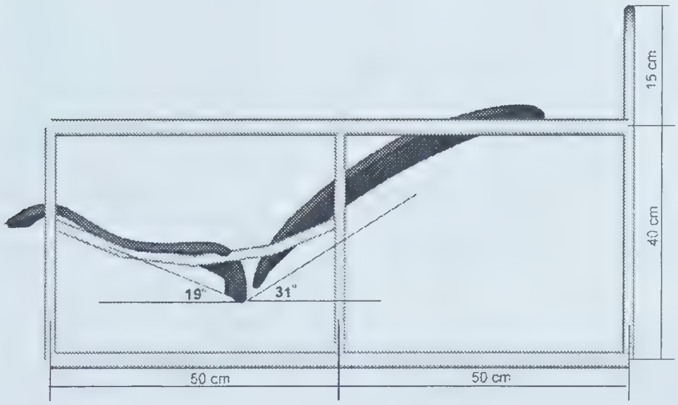


Figure 35

2. Heat reduction design

To minimize the heat load on the driver, my design incorporates the application of a commercial automobile window tinting film to the top half of the canopy to reflect some of the incident sunlight.

Ducted air is another way of cooling the driver. SCUA's ducted air vents point directly at the driver's jugular vein, which is the most effective way to cool the driver.

3. Control interface design

To date, I have not been provided with information from the instrumentation group. When the information is available I can complete that portion of the cockpit design.

7 Design for fabrication

The shell and frame of the solar car are two major components that need to be fabricated from the ground up.

The frame is made of welded aluminum tube. Comparatively, the construction of the shell is quite different and more difficult. The shell is made up of body, canopy and spats. The canopy will be custom made, by drape-molding a polycarbonate over a plug. The fabrication of the body and the spats is done in moulds. First a plug is made in the exact form as the finished body. Then molds are made from the plug. Finally, the shell parts are laid up in the molds. These stages require fabrication care and control.

7.1 Plug construction

1. CNC routing

The SCUA was molded with the computer program called Rhino3D. Once the shape of SCUA was determined, the Rhino3D model is transferred to the MasterCAM computer program, in which the model was turned into NC-code. NC-code directs the running of the CNC router. When all the pieces of plug are cut and put together, a rough plug results.

The CNC router we use is the 'Phoenix GS 510 HDR'. The working dimension of this type is X: 140 cm, Y: 300 cm and Z: 18 cm. So the working height is limited. Another limitation of this machine is that it can only be operated in the X, Y and Z axis. That is to say, it doesn't have a local axis system. It can not mill a piece of material from underneath.

The material for the plug is HI-100 blue high density Styrofoam. Each piece is 8' x 2' x 2". We chose this material over other materials, such as MDF, low density Styrofoam, urethane foam, etc, because it is extremely suitable and tough—it can be finished smooth yet is soft enough for quick prototyping. It is light, which is also ideal for quick prototyping.

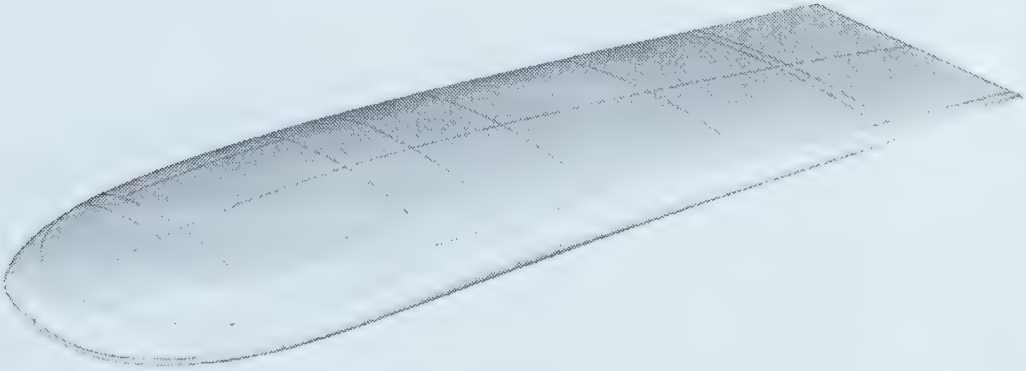


Figure 36. Computer 'Sliced' body parts

In the computer the body form is 'sliced' into 18 major pieces and 15 small pieces which are then transferred to the CNC router which mills them separately.

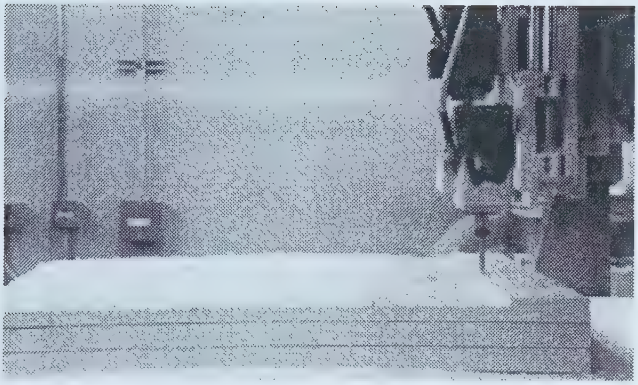


Figure 37. CNC Router in operation

2. Form the plug

Figure 38. The Styrofoam pieces formed the nose of the plug

Because of the organic shape and the number of parts, the exactness of fit is critical. A 2-rail frame structure was designed for putting all the pieces together.

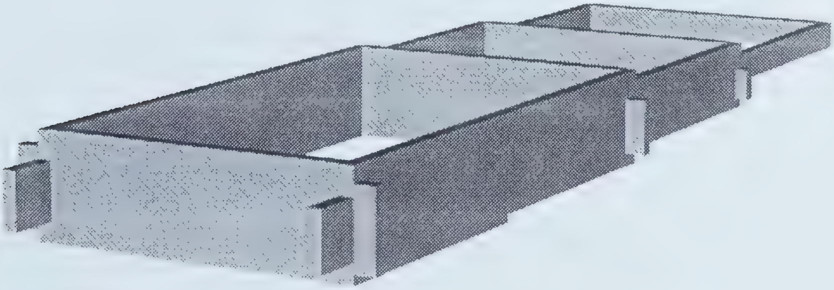


Figure 39. The 2-rail frame

The rails and the cross-sections are a sandwich structure with 1/16" plywood as surface material and Styrofoam as core material with epoxy as adhesive. The frame is light, strong and easy to cut. Another advantage is that core Styrofoam easily adheres to external pieces.

After all of the pieces are put together and fine sanded, we hand lay up 2 layers of fiberglass using epoxy, as other resin would dissolve the Styrofoam. The epoxyed form is strong and can be sanded very smooth.

The finish of the plug determines the finish of car body. The final requirement for the car body is class 'A' finish (best level of autobody finish), which is very critical. Hence, the quality of the finish of the plug is essential.

At last the plug is taken to an autobody shop for the application of finish 'A'.

7.2 Mold fabrication

First, the location of the part lines is determined. The part lines are located according to actual body parts--top, bottom and nose. Because the nose is too long, it would be very hard for the mold to be popped off the plug. So the nose is divided into top and bottom pieces.

Second, coat the plug with release agent.

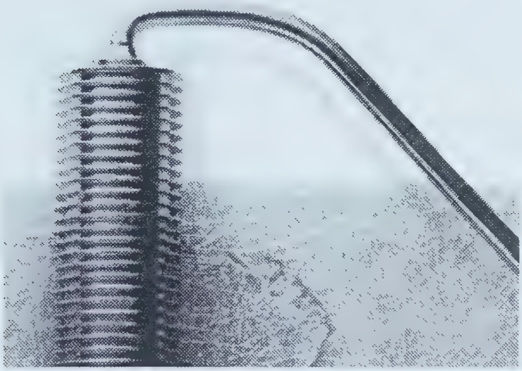


Figure 40. Hand lay up fiberglass with resin using a roller

Third, hand lay up fiberglass with resin. The order is mat/roving/mat laminated with polyester matrix. The cold cure process normally takes 24 hours in a vacuum bag to ensure the resin is evenly distributed. Before molds are put into the vacuum bag, the excessive resin will be absorbed by fiberglass.

Last, the molds are popped off the plug and sanded very carefully for future use.

7.3 Shell fabrication

1. Stages for fabrication

-Coat mold with release agent.
-Hand cut pieces of carbon fiber.
-Lay up 2 layers of carbon fiber with polyester.
-Use fiberglass to absorb excessive resin.
-Cure parts in Autoclave for 12 hours.
-Pop the shell parts off.
-Fill the cracks and sand the parts.
-Remove excessive edges.

2. Modification of shell parts

When modifying the top and bottom pieces, Nomex honeycomb is cut into exact sized pieces and fitted onto the surface to form ribs. Then one layer of carbon fiber is laid up over them and the part is sent to the autoclave to cure for 12 hours. This results in the sandwich structure ribs.

A laser cutter is used for cutting holes in the top body component. The solar module is encapsulated by Tedlar, polyvinyl fluoride, and only is 1 mm thick. With the encapsulation of Tedlar, the solar module becomes flexible and can be fitted onto the contour of the top body component.

Kevlar is added in some critical local areas. These are the lowest part of the bottom (about 1.5 m^2), the front part of rear spats and the back parts of front spats. The technique of applying Kevlar resembles that of applying carbon fiber. One layer of Kevlar is laid up over the critical area and cured in an autoclave.

3. Connection between space-frame and body

Four 5.5" diameter 1/16" thick sheet metal will be glued to the carbon body. The bolts will be passed through the sheet in advance. Another layer of carbon will be applied later to several areas to ensure the structure is strong enough. Bolts are passed through rubber mounts to the frame from underneath to minimize vibration.

4. Color consideration

To achieve the best vehicle efficiency, the temperature of the solar car components should be minimized. For example, some solar cars have significantly changed their shapes by the time they reached the finish because heat has deformed the composites. Also, the battery works best if the temperature is not too high. Last, the most fragile component, the driver, can't endure high temperatures while driving under June's sun. Hence, we selected silver metal paint for body and spats because it is the most reflective. The shell parts are taken to an autobody shop again and to be sanded and painted repeatedly. Finish 'A' is finally achieved.

8 Discussion of design

8.1 Discussion of shell design and cockpit design

Solar array is one of the major factors that determine the shape of the shell. At the beginning of the design process, we couldn't obtain the flexible solar module to mount to SCUA. Hence, the model 1 and model 2 have a fairly flat top. Their aerodynamics weren't satisfactory. They resembled the Solar Eagle III.

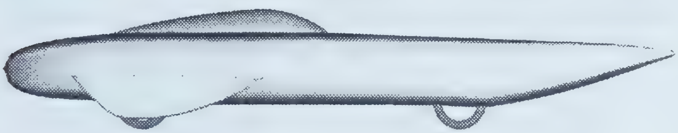


Figure 41. Side view of model 2

An important change came in the beginning of August after the Solarex Company donated the advanced solar array we needed for the project. The solar module was custom made. It is flexible and has a better refractive index matching because of the Tedlar encapsulation. As shown in model 3, the shape became very streamlined. The Cd (coefficient of drag) is 0.062 (Appendix), which is much improved. Only slight changes have been made since.

1. The changes from model 3 to model 4

The height of the body was reduced by 10 cm, from 65 cm to 55 cm, which reduced the frontal area thus improving its aerodynamics. It is calculated that 1 cm^2 of drag area equals 1 minute in race finish time. The curvature from front to trail became flatter because of the height reduction, which resulted in the improvement of solar array efficiency and the convenience of solar module mounting.

The body was shortened by 40 cm, from 600 cm to 560 cm. According to the textbook, the ideal aerodynamic length-to-thickness ratio is 4:1. However, this ideal is physically impossible. Our ratio is 10:1. The reduction of the length also led to diminishing the wetted area amounting to 1.6 m^2 (0.4 m x 2 m x 2), which also has better aerodynamics.

Both changes have shrunk the volume of the body, and reduced its weight.

The nose was sharpened because the Cp (pressure coefficient) map (Appendix) showed that there was a blue region which meant positive pressure.

The body was lowered by 11 cm, from a 35-cm clearance over the ground to 24 cm, in order to reduce the difficulty of suspension design.

2. The changes from model 4 to model 5

The high absolute values of Cl had been a large problem in model 3 (-0.33) and model 4 (-0.43).

Figure 42. Cross-section

From the cross-section in the middle of the car it can be seen that the lower arch is longer than the upper arch. This is the major cause of negative lift. If the top surface were bent any more, the mounting of the solar array would be difficult. In the aerodynamics of a form, everything is related. A slight change in any local area will affect the whole body. Therefore, I chose to find another solution.

In the Cp map, there was negative pressure over the front region of the front spats, which indicated that the front spats probably should be moved forward. Furthermore, there was a vortex of wake implying positive pressure in the trail region (Appendix). Dropping the trail might overcome the problem. Fortunately, my assumption was somewhat tested by pitching a 1° angle of model 4, changing the Cl from –0.43 to –0.25. Of particular interest is that the change of 1° pitch results in keeping the nose and the trail at the same horizontal level.

Figure 43. Profile modification

Finally, the trail was dropped by 8 cm to keep the nose and the trail even instead of pitching it 1°. The body was raised again to 35-cm clearance to overcome road effect and lengthened to 580 cm to fit the solar array.

The result was excellent. The Cl of model 5 was only –0.0014 and the Cd was still as low as 0.062, which is shown in the Cp map of model 5. The whole model is totally green, which demonstrates that the pressure is even. Richard Butchart, EDS Sunrayce Aerodynamics Leader, said "the basic body shape is nice and smooth and the range of pressures is over a small band. You actually have a very good looking design compared with most teams at this time."

8.2 Discussion of design for fabrication

Some sandwich structure ribs were added to the top and bottom parts of the body. Thus, our shell structure has the characteristic of a 'tub' structure. The rigidity is advantageous and beneficial for vibration reduction and better fitting. Good sealing is important for aerodynamics. What's more, the ribs add very little additional weight.

The data I collected for maximizing carbon fiber properties means curing according to a certain temperature, pressure and time, usually in an autoclave. In the actual fabrication process, we have no access to an autoclave or a vacuum bag. Although we will use a room temperature resin, call 'cold cure'. The result can't be fully known until the car endures a 10-day race under June' strong sunlight without deformation.

9. Conclusion

The solar module is still a critical aspect of solar car performance. Some teams, like Honda 'Dream', have obtained solar cells that can be fitted all over the body surface, thus greatly reducing the surface area of the car. Another interesting discovery is that the output of the solar array is improved almost 30 % with raindrops on it. But they are heavy, have bad aerodynamics and are not always available. Encapsulation can also improve refractive index matching but also needs to improve.

The 'Tub' structure has been widely used in the solar cars. A 'tub' structure is potentially lighter and more rigid than a space-frame structure. A 'tub' structure might be an improvement in SCUA II. To date, I haven't seen a unified body structure for a solar vehicle as is found in normal modern cars. Whole-body structure should be more rigid because of its eggshell metaphor, thus can be lighter. It would, however, present a challenge for fabrication and repair. But it deserves to be explored.

The effort to design and build a solar car expresses our effort to improve our environment. I think it should also be expressed in our design in terms of making use of natural resources. Balsa, bamboo and rice paper are examples that have been used in other solar cars, mostly for structure. The harnessing of wind power has also been applied in a solar car called the 'Pumpkinseed'.

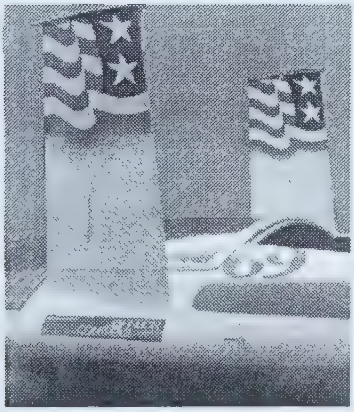


Figure 44 The picture shows the fins of the 'Pumpkinseed'.

My solar car body design is presently being fabricated. This portion of the design management plan is behind schedule. However, I expect fabrication to be completed by the end of this calendar year. This will make it possible to finish the cockpit and seating components of my design in time for spring testing and modification. I am excited to see the total design completed in time for the race and will continue to work until my colleague in Engineering toward that goal.

The SCUA is first solar energy powered vehicle that has been designed at this University. The other team members and I feel the design is intelligent and embodies the design and technological features that will make it a viable competitor.

Solar cars and the races that feature them are competitions of design and engineering intelligence. A lot of technological improvements have emerged in the races that have been applied in electric vehicles and other areas of transportation. As an industrial designer, I have advanced my education and experience through this whole design process and through my cooperation with the team members from other disciplines.

Bibliography

Gibson, R. F.
Principles of Composite Material Mechanics, 1994

Gorden, E. J.
The New Science of Strong Materials or Why You Don't Fall Through the Floor, 1976
Structures, 1978

Hoerner, S. F.
Fluid-Dynamic Drag, 1965

Massey, B. S.
Mechanics of Fluids, 1968

Mufti (Edited by), A. A.; Erki, M-A & Jaeger, G. L.
Advanced Composites Materials-with Application to Bridges, 1991

Norbye, P. Jan
Streamlining and Car Aerodynamics, 1977

Robins, C. Richard
Canadian Nature Guides-Saltwater Fish

Roche, M. David; Schinckel, E. T. Antony; Storey, W. V. John; Humphris, P. Clive & Guelden. R. Michelle
Speed of Light-The 1996 World Solar Challenge

Scibor-Rylski, J.A..
Road Vehicle Aerodynamics

Internet Resources (Effective until December, 1998)

African Solar Electric Car Race homepage

American Tour de Sol homepage

Auburn University homepage

California Polytechnic State University - San Luis homepage

Canadian Solar Discovery Challenge homepage

Clarkson University homepage

Concordia University homepage

Conestoga College homepage

Drexel University homepage

École de technologie supérieure homepage

EDS company homepage

Fiberglast company homepage

Florida State University College of Engineering homepage

Georgia Institute of Technology homepage

Howard University homepage

Iowa State University homepage

Kansas State University homepage

Lincoln Land Community College homepage

Massachusetts Institute of Technology homepage

McGill University homepage

McMaster University homepage

Mercer University homepage

Messiah College homepage

Michigan Technological University homepage

Middle Tennessee State University homepage

New Mexico Institute of Mining and Technology homepage

North Dakota State University homepage

Northwestern University homepage

Ohio State University homepage

Prairie View A&M University homepage

Principia College homepage

Purdue University homepage

Queen's University homepage

Rose-Hulman Institute of Technology homepage

South Dakota School of Mines & Technology homepage

Sunrayce homepage

Taylor University homepage

Texas A&M University homepage

United States Military Academy homepage

Université du Québec à Montréal homepage

University of Alberta homepage

University of Arizona homepage

University of Idaho homepage

University of Illinois homepage

University of Michigan homepage

University of Minnesota homepage

University of Missouri-Columbia homepage

University of Missouri-Rolla homepage

University of North Dakota homepage

University of Notre Dame homepage

University of Oklahoma homepage

University of Pennsylvania homepage

University of Texas at Austin homepage

University of Toronto homepage

University of Waterloo homepage

University of Western Ontario homepage

University of Wisconsin - Platteville homepage

Virginia Western Community College homepage

Western Michigan University homepage

Winona State and Mankato State Universities homepage

Winston Solar Challenge homepage

World Solar Car Rallye homepage

World Solar Challenge homepage

Yale University homepage

York University homepage

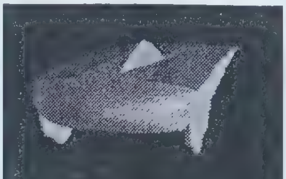
Appendix: VSAERO Analysis of Each Computer Models

1.The aerodynamic configurations of each model

One file deals with one model. These pages were printed directly from the coded web pages.

EDS
Service Request
00287

Description:	first model
Institution:	University of Alberta
Requested by:	Xiaoyu Zhou
Email/Phone:	solarcar@gpu.srv.ualberta.ca
Event/Year:	Sunrayce 1999
Date Logged:	04/21/98
Date Completed:	06/10/98



solar1.dxf

Task No. **01** **Aero**

VSAERO INPUTS - ONSET CALCULATIONS

Yaw Angle:	0.0 deg	Velocity(V):	50.0 mph	73.33 fps	80.05 kph
Pitch Angle:	0.0 deg	Length(CBAR):	150 in	12.5 ft	3.81 m
Trip Location:	None m	Semi Span(SSPAN):	23.63 in	1.97 ft	0.60 m
Viscosity(u):	.00016	Frontal Area(SREF):	914.5 in^2	6.34 ft^2	0.59 m^2

Reynolds Number(Rn): 5.73 (CBAR*V/u)

Moment Reference Location(REFMX): 0.00 (REFMY): 0.00 (REFMZ): 0.00

VSAERO OUTPUTS - RESULTS CALCULATIONS

Coefficient of Drag (Cd):	0.1157	X Axis Moment (CMX):	0.4198E-02
Coefficient of Side (Cs):	-0.4314E-03	Y Axis Moment (CMY):	0.5550
Coefficient of Lift (Cl):	-0.8611	Z Axis Moment (CMZ):	-0.1312E-02
Surface Friction Drag (CSFD):	0.5125E-01	VSAERO Wetted Area Output(m^2):	18.831
Boundary-Layer Pressure Drag from Momentum:	-0.8730E-02	ACTUAL Wetted Area:	17220.94 in^2
		(VSAERO Wet Area*SREF)	119.54 ft^2
Integrated Squire-Young Drag:	0.5666E-01		11.110289999999999 m^2

VSAERO OUTPUTS - IMAGE FILES

Front View - Cp	287_01G01.gif	Top Iso View - Off Body Strmlns	287_01G07.gif
Top View - Cp	287_01G02.gif	Bottom Iso View - Cf Strmlns	287_01G08.gif
Bottom View - Cp	287_01G03.gif	Graph - Cd & Cl	287_01G09.gif
Side View - Cp	287_01G04.gif	Graph - Cp & Phi	287_01G10.gif
Side View - Off Body Cp	287_01G05.gif	Graph - Cp & H Upr Strmlns	287_01G11.gif
Top Iso View - Cf Strmlns	287_01G06.gif	Graph - Cp & H Lwr Strmlns	287_01G12.gif

Streamlines for graph G11 (Upr Inbd): 67 (Upr Outbd): 74 & graph G12(Lwr Inbd): 110 (Lwr Outbd): 106

EDS
Service Request
00382

Description:	last version of car model
Institution:	Univ of Alberta
Requested by:	Xiaoyu Zhou
Email/Phone:	xz@ualberta.ca
Event/Year:	Sunrayce 1999
Date Logged:	08/05/98
Date Completed:	08/06/98

Task No.
01
Aero

VSAERO INPUTS - ONSET CALCULATIONS

Yaw Angle:	0.0 deg	Velocity(V):	50.0 mph	73.33 fps	80.05 kph
Pitch Angle:	0.0 deg	Length(CBAR):	216.54 in	18.05 ft	5.50 m
Trip Location:	None m	Semi Span(SSPAN):	39.37 in	3.29 ft	1.00 m
Viscosity(u):	.00016	Frontal Area(SREF):	1705 in^2	11.83 ft^2	1.10 m^2

Reynolds Number(Rn): 8.27 (CBAR*V/u)

Moment Reference Location(REFMX): 0.00 (REFMY): 0.00 (REFMZ): 0.00

VSAERO OUTPUTS - RESULTS CALCULATIONS

Coefficient of Drag (Cd):	0.6157E-01	X Axis Moment (CMX):	-0.6124E-04
Coefficient of Side (Cs):	0.5503E-03	Y Axis Moment (CMY):	0.1408
Coefficient of Lift (Cl):	-0.3303	Z Axis Moment (CMZ):	0.1787E-02
Surface Friction Drag (CSFD):	0.5340E-01	VSAERO Wetted Area Output(m^2):	22.619
Boundary-Layer Pressure Drag from Momentum:	0.2432E-02	ACTUAL Wetted Area:	38565.39 in^2
Integrated Squire-Young Drag:	0.6793E-01	(VSAERO Wet Area*SREF)	267.71 ft^2
			24.8809 m^2

VSAERO OUTPUTS - IMAGE FILES

Front View - Cp	382_01G01.gif	Top Iso View - Off Body Strmlns	382_01G07.gif
Top View - Cp	382_01G02.gif	Bottom Iso View - Cf Strmlns	382_01G08.gif
Bottom View - Cp	382_01G03.gif	Graph - Cd & Cl	382_01G09.gif
Side View - Cp	382_01G04.gif	Graph - Cp & Phi	382_01G10.gif
Side View - Off Body Cp	382_01G05.gif	Graph - Cp & H Upr Strmlns	382_01G11.gif
Top Iso View - Cf Strmlns	382_01G06.gif	Graph - Cp & H Lwr Strmlns	382_01G12.gif

Streamlines for graph G11 (Upr Inbd): 61 (Upr Outbd): 68 & graph G12(Lwr Inbd): 99 (Lwr Outbd): 73

EDS
Service Request
00385

Description:	last version 6 inches lower
Institution:	Univ of Alberta
Requested by:	Xiaoyu Zhou
Email/Phone:	xz@ualberta.ca
Event/Year:	Sunrayce 1999
Date Logged:	08/07/98
Date Completed:	08/07/98

Task No.
01
Aero

VSAERO INPUTS - ONSET CALCULATIONS

Yaw Angle:	0.0 deg	Velocity(V):	50.0 mph	73.33 fps	80.05 kph
Pitch Angle:	0.0 deg	Length(CBAR):	216.54 in	18.05 ft	5.50 m
Trip Location:	None m	Semi Span(SSPAN):	39.37 in	3.29 ft	1.00 m
Viscosity(u):	.00016	Frontal Area(SREF):	1550 in^2	10.76 ft^2	1.00 m^2

Reynolds Number(Rn): 8.27 (CBAR*V/u)

Moment Reference Location(REFMX): 0.00 (REFMY): 0.00 (REFMZ): 0.00

VSAERO OUTPUTS - RESULTS CALCULATIONS

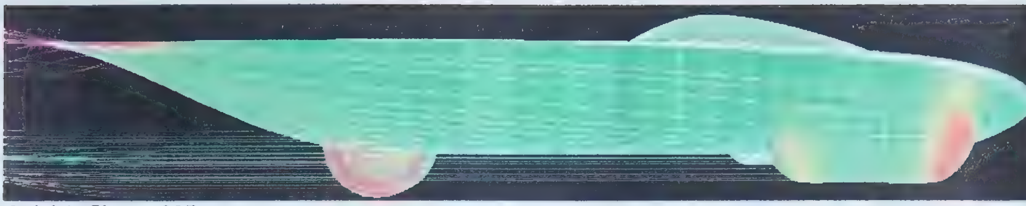
Coefficient of Drag (Cd):	0.5785E-01	X Axis Moment (CMX):	0.2435E-02
Coefficient of Side (Cs):	-0.1985E-02	Y Axis Moment (CMY):	0.1705
Coefficient of Lift (Cl):	-0.4338	Z Axis Moment (CMZ):	-0.7483E-02
Surface Friction Drag (CSFD):	0.5210E-01	VSAERO Wetted Area Output(m^2):	23.259
Boundary-Layer Pressure Drag from Momentum:	0.2083E-02	ACTUAL Wetted Area:	36051.450000000004 in^2
Integrated Squire-Young Drag:	0.5667E-01	(VSAERO Wet Area*SREF)	250.26000000000002 ft^2
			23.259 m^2

VSAERO OUTPUTS - IMAGE FILES

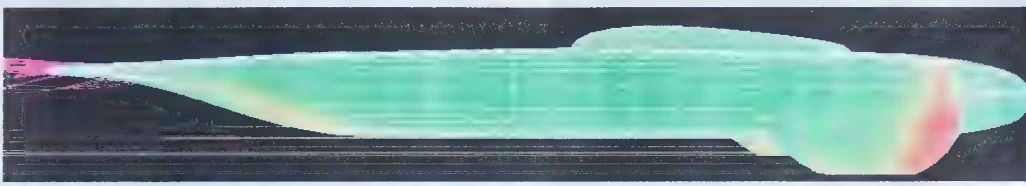
Front View - Cp	385_01G01.gif	Top Iso View - Off Body Strmlns	385_01G07.gif
Top View - Cp	385_01G02.gif	Bottom Iso View - Cf Strmlns	385_01G08.gif
Bottom View - Cp	385_01G03.gif	Graph - Cd & Cl	385_01G09.gif
Side View - Cp	385_01G04.gif	Graph - Cp & Phi	385_01G10.gif
Side View - Off Body Cp	385_01G05.gif	Graph - Cp & H Upr Strmlns	385_01G11.gif
Top Iso View - Cf Strmlns	385_01G06.gif	Graph - Cp & H Lwr Strmlns	385_01G12.gif

Streamlines for graph G11 (Upr Inbd): 57 (Upr Outbd): 63 & graph G12(Lwr Inbd): 91 (Lwr Outbd): 70

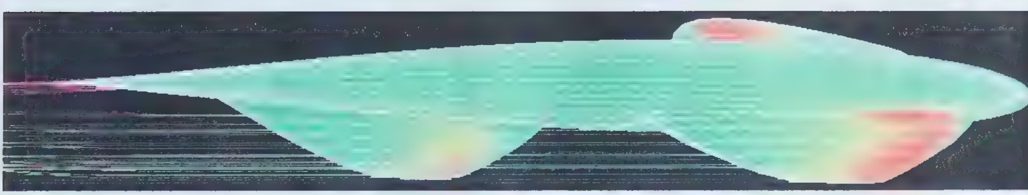
2: Cp map of side view



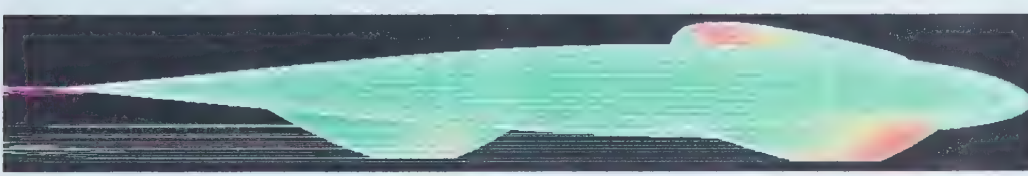
Model 1, file no. 287



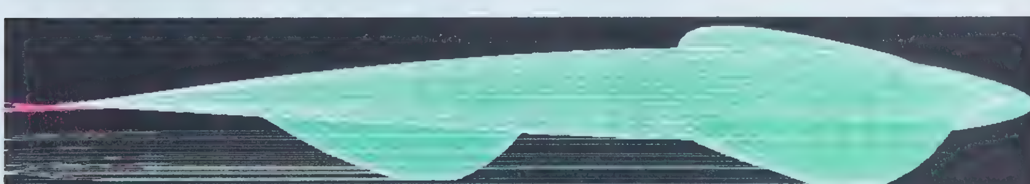
Model 2, file no. 359



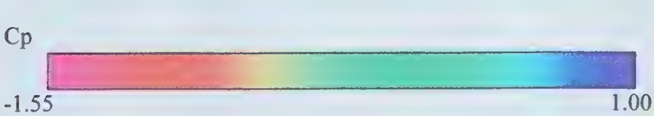
Model 3, file no. 382



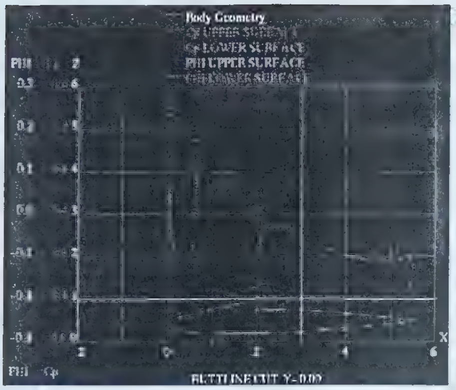
Model 4, file no. 385



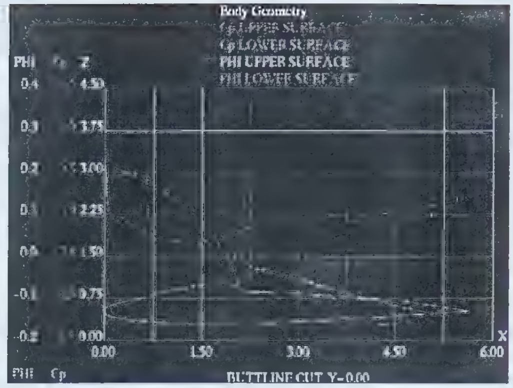
Model 5, file no. 384



3. Cp & Phi Map

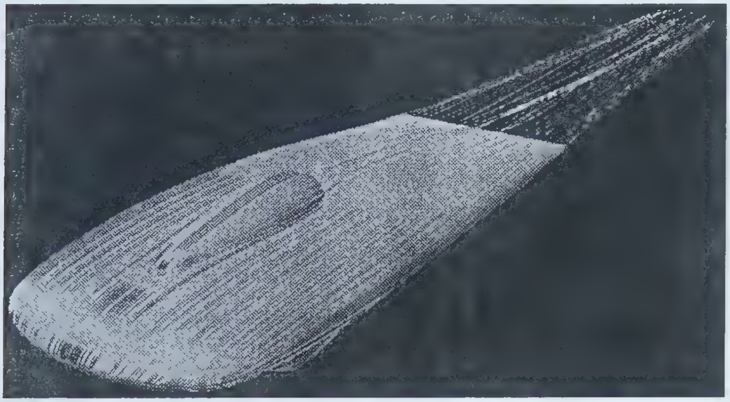


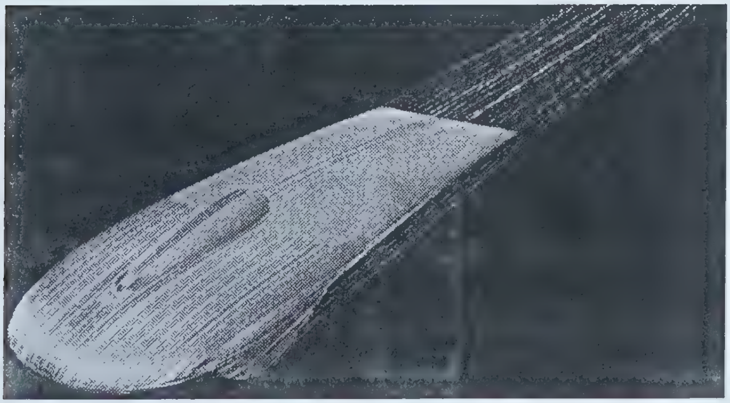
Model 4



Model 5

Cp & Phi (configuration of viscosity) maps of model 4 and model 5


Model 4


Model 5

Cp maps of isometric top views of model 4 and model 5

Design for SCUA

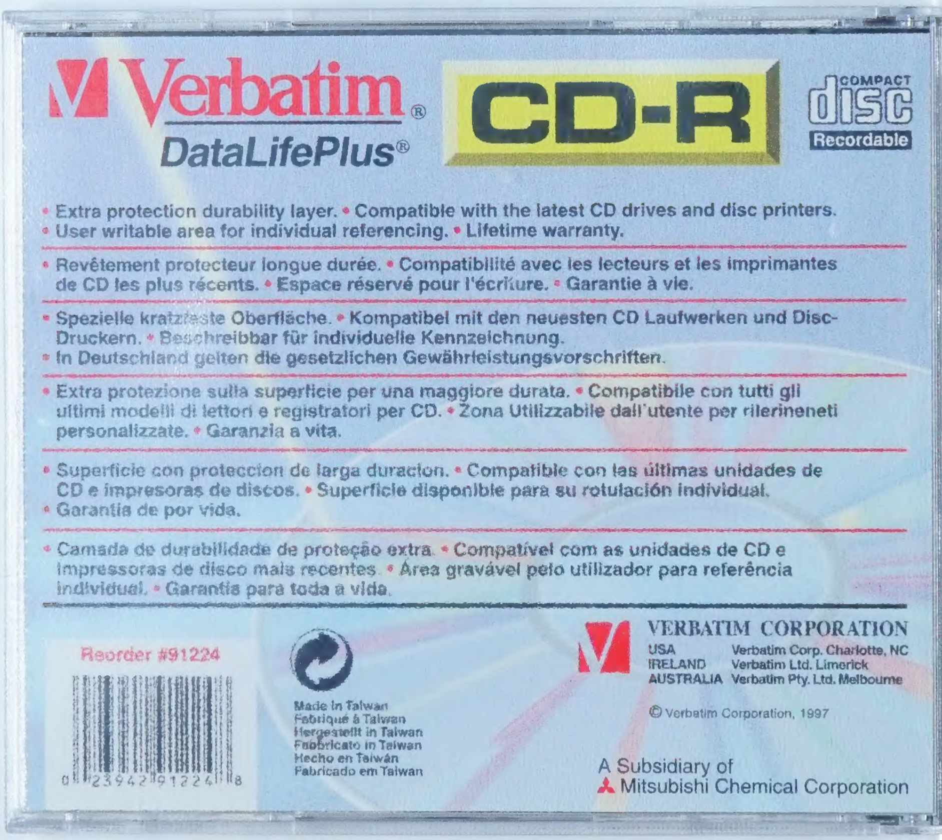
Solar Car of the University of Alberta

By

Shawyu Zhou

Industrial Design
Department of Art and Design
University of Alberta

December, 1998


Verbatim®
DataLifePlus®
CD-R
COMPACT disc Recordable
• Extra protection durability layer. • Compatible with the latest CD drives and disc printers.
• User writable area for individual referencing. • Lifetime warranty.
• Revêtement protecteur longue durée. • Compatibilité avec les lecteurs et les imprimantes de CD les plus récents. • Espace réservé pour l'écriture. • Garantie à vie.
• Spezielle kratzfeste Oberfläche. • Kompatibel mit den neuesten CD Laufwerken und Disc-Druckern. • Beschreibbar für individuelle Kennzeichnung.
• In Deutschland gelten die gesetzlichen Gewährleistungsvorschriften.
• Extra protezione sulla superficie per una maggiore durata. • Compatibile con tutti gli ultimi modelli di lettori e registratori per CD. • Zona Utilizzabile dall'utente per rilerineneti personalizzate. • Garanzia a vita.
• Superficie con proteccion de larga duracion. • Compatible con las últimas unidades de CD e impresoras de discos. • Superficie disponible para su rotulación individual.
• Garantia de por vida.
• Camada de durabilidade de proteção extra. • Compatível com as unidades de CD e impressoras de disco mais recentes. • Área gravável pelo utilizador para referência individual. • Garantia para toda a vida.
Reorder #91224
0 23942 91224 8
Made in Taiwan
Fabriqué à Taiwan
Hergestellt in Taiwan
Fabbricato in Taiwan
Hecho en Taiwán
Fabricado em Taiwan
VERBATIM CORPORATION
USA Verbatim Corp. Charlotte, NC
IRELAND Verbatim Ltd. Limerick
AUSTRALIA Verbatim Pty. Ltd. Melbourne
© Verbatim Corporation, 1997
A Subsidiary of
Mitsubishi Chemical Corporation